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TRANSACTIONS

OF THE

ILLUMINATING ENGINEERING SOCIETY

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32 VICTORIA STREET
LONDON SW1

NOTES ON RECENT MEETINGS AND EVENTS

General Meetings in London.

A meeting of the Society was held in the Lecture Theatre of the Institution of Mechanical Engineers (Storey's Gate, St. James's Park, London, S.W.1) on Tuesday, April 12, 1938. The chair was taken by the President (Dr. S. English) at 7 p.m.

The minutes of the last meeting having been taken as read, the President then called upon Mr. J. W. Ryde to present his paper entitled "Luminescent Materials and their Application to Light Sources," which was illustrated by lantern slides and numerous striking demonstrations. On the motion of the President, a vote of thanks was accorded to the author for his paper, and an interesting discussion ensued, in which the following took part: Mr. F. E. Lamplough, Mr. L. J. Davies, Mr. J. T. Anderson, Mr. G. H. Wilson, Mr. J. S. Dow, Dr. S. English, Mr. S. J. Patmore, Mr. W. J. Scott, Mr. R. O. Sutherland, and Mr. A. W. Beuttell.

After Mr. Ryde had replied to the discussion, the President mentioned that two members of the Society, Dr. C. C. Paterson and Mr. G. H. Wilson, were leaving for a visit to the United States on the following day. The members present cordially endorsed his suggestion that good wishes for the journey should be conveyed to these two gentlemen, coupled with the request that they should carry fraternal greetings from the Society to the Illuminating Engineering Society in the United States.

Applications for Membership.

At the general meeting of the Society, held on April 12, 1938, the names of the following applicants for membership were presented:—

Elections Pending.

CORPORATE MEMBERS:—

Bateman, C. .....Harrogate Gas Company, Harrogate, YORKS.

Blackburne-Maze, L. M. ...Central London Electricity, Ltd., 143, Regent Street, LONDON, W.1.

Carpenter, A. J. .....Harcourts, Ltd., 6, York Place, LEEDS, 1.

Crane, W. C. .....Central London Electricity, Ltd., 63-81, Pelham Street, LONDON, S.W.7.

Crocott, A. .....13, Norton Road, Roundhay, LEEDS.

Hayward, J. R. G. ...Central London Electricity, Ltd., 65, South End Close, Hampstead, LONDON, N.W.3.

Horstmann, B. G. .....Albion Works, BATH.

Humphreys, A. E. ...7, St. James Street, LONDON, S.W.1.

Johnson, F. C. .....159, City Road, Edgbaston, BIRMINGHAM.

Lemon, E. O. .....Central London Electricity, Ltd., 63-81, Pelham Street, LONDON, S.W.7.

Margetson, P. C. .....21, St. Peter's Road, Handsworth, BIRMINGHAM, 20.

Mayall, J. W. .....61, Moor Street, BIRMINGHAM, 4.

Oldershaw, R. W. ...23, Hadley Way, Winchmore Hill, LONDON, N.21.

Pickering, R. .....149, Manor Drive North, Worcester Park, SURREY.

Pritchard, C. A. .....Central London Electricity, Ltd., 60, St. Martin's Lane, LONDON, W.C.2.

Sparks, G. .....3, Albany Court, 1, Prince Albert Road, LONDON, N.W.1.

Twiss, J. M. .....Birchen Avenue, Ossett, YORKS.

Walker, S. .....29, Tranby Avenue, Hessle, E. YORKS.

ASSOCIATES:—

Kenworthy, H. E. ...181, Lansdown Road, Tottenham, LONDON, N.17.

Spalding, J. Howard...Lynwood, Rockshaw Road, Merstham, SURREY.

COUNTRY MEMBERS:—

Allderidge, C. J. .....10, Bascobel Road, WALSALL.

Bates, G. .....St. Patricks, 314, Howth Road, Raheny, DUBLIN.

Barclay, W. J. .....3, Woodliffe Crescent, Chapel Allerton, LEEDS, 7.

Brangwin, K. C. .....10, Ivy Road, Wylde Green, BIRMINGHAM.

Caunt, C. S. .....62, Thackeray's Lane, Woodthorpe, NOTTINGHAM.

Drake, W. E. J. .....High View, Grove Street, Retford, NOTTS.

Field, P. L. .....176, Northfield Road, Kings Norton, BIRMINGHAM.

Freeman, C. F. .....84, Green Lane, COVENTRY.

Latham, A. .....Electricity Works, Mansfield, NOTTS.

Lovell, R. A. .....18, Cubley Road, Hall Green, BIRMINGHAM.

Merris, A. A. .....Greengates, Alcester Road, Wythall, WORCS.

Meylan, A. J. .....19, Moor Grange Drive, West Park, LEEDS, 6.

Morley, G. H. .....381, Stanningley Road, Bramley, LEEDS.

Moseley, A. J. .....112-114, Queen Victoria Road, COVENTRY.

Montgomery, R. .....82, Rothesay Avenue, NOTTINGHAM.

Murrell, P. .....24, Clarendon Place, LEEDS, 2.

Nott, G. S. .....71, Shakespeare Street, COVENTRY.

Pimm, A. J. .....75, Robinhood Lane, Hall Green, BIRMINGHAM.

Punter, H. .....112, Castlecroft Road, WOLVERHAMPTON.

Ross, A. .....Blane View, Coltpark Avenue, Bishopbriggs, GLASGOW.

Shaw, S. .....32, Green Bank Avenue, Hall Green, BIRMINGHAM, 28.

Slater, A. .....61, St. Mary's Row, Moseley, BIRMINGHAM.

Tait, W. L. .....274, Bath Street, GLASGOW, C.2.

Wallis, A. E. B. .....Greenways, Green Road, Moseley, BIRMINGHAM.

Elections Completed.

At this meeting the names of those announced on March 1, which were published in the issue of the *Transactions* (Vol. III., No. 3, March, 1938, p. 47), were presented again, and these applicants were formally declared members of the Society.

The Annual Dinner.

The Annual Dinner, held at the Trocadero Restaurant, on March 21, proved once more to be a very popular event. The toast of "The Illuminating Engineering Society" was proposed by Sir Alexander Maxwell (Permanent Under-Secretary, Home Office), and was responded to by the President (Dr. S. English). The toast of "The Guests" was proposed by Mr. Percy Good, and responded to by Sir David Munro, Secretary of the Industrial Health Research Board.

Sectional Meetings.

Public Lighting Section. On March 4, at a meeting held at Watson House, London, S.W., a discussion on the technical aspects of the M.O.T. Street Lighting Report was opened by Mr. A. R. McGibbon and Mr. G. S. C. Lucas.

Decorative Lighting Section. An address by Miss Edna Mosely on "How I would plan the Lighting for a Home" was given at Gas Industry House on March 22 and led to an entertaining discussion.

Industrial Lighting Section. An original type of meeting was arranged in the lecture theatre of the Home Office Industrial Museum, Westminster, on March 29, when a discussion on the Lighting Provisions of the new Factory Act took place. Introductory statements, expressing distinctive points of view, were made by Mr. D. Gluckstein (Messrs. J. Lyons and Co., Ltd.), Mr. H. N. Winbolt (National Safety First Association), Dr. S. English (President of the Illuminating Engineering Society), and Mr. E. W. Murray (Home Office Industrial Museum). There was a large attendance, and an informative exchange of views, in which members present also joined.

Formation of new Informal Local Centre for the Midland Area.

At a meeting held at the Grand Hotel, Birmingham, on April 8, a resolution was passed unanimously approving the formation of a fifth informal local centre for the Midland area, with headquarters in Birmingham. Introductory addresses were given by Mr. A. Cunnington (Vice-President) and Mr. J. S. Dow (Hon. Secretary), from London. The proposal, put to the meeting by Mr. Howard Long, who presided, was strongly supported by local members of the Society. An organising committee, with Mr. Howard Long as chairman and Mr. A. E. B. Wallis as hon. secretary, was elected. Suggestions for meetings and social events were made, and the committee was entrusted with the task of preparing a programme for the session, to commence in October next.

Meetings of Local Centres.

A number of meetings arranged by local centres have taken place during the past month. A paper on Colliery Lighting was read by Mr. J. W. Howell at a gathering of the North-Western Area local centre in Manchester. In Glasgow, on March 2, Mr. H. E. de Weerdt delivered a lecture on "Automatic Control of Illumination," which led to a keen discussion, opened by Mr. M. W. Hime. In Dublin, on March 1, Mr. H. Ayre Purdie lectured on "Colour Lighting in Theatres and Cinemas," illustrating his remarks by numerous lantern slides and demonstrations.

A new departure was the successful annual dinner arranged by the North Midland Centre in Leeds on March 21, to which the President and Honorary Secretary from London (Dr. S. English and Mr. J. S. Dow), and the Chairman and Honorary Secretary of the North-Western Local Centre (Mr. R. C. Hawkins and Mr. J. Sellars) were invited. Councillor Sellars presided over the dinner, the first of its kind, which it is hoped will become an annual event.

Annual General Meeting

The annual general meeting will be held in the Lecture Theatre of the Institution of Mechanical Engineers, Westminster, S.W.1., on Tuesday, May 10, at 7 p.m., when the annual report of the Council and the accounts for the past year will be presented for adoption and auditors for the coming session will be elected.

At the conclusion of formal business an address, reviewing lighting developments in Belgium, will be given by Mr. E. Uytborck (Directeur Général du Comité d'Etudes Techniques de la production et de la distribution d'électricité en Belgique).

Obituary

JOHN R. HEPPLE.

We record with great regret the death of Mr. John R. Hepple, who passed away on March 22. Mr. Hepple, who was associated with the Newcastle-upon-Tyne and Gateshead Gas Company, was a member of the Society of long standing, and had recently consented to accept nomination on the Council.

THE PHOTOMETRY OF PROJECTORS

By W. M. HAMPTON, Ph.D., B.Sc., F.Inst.P. *(Member).*

(Read before the Photometry Section, Illuminated Engineering Society, on November 23rd, 1937.)

When the author was invited to contribute a paper to this section on the subject of "The Photometry of Projectors," it was felt that it would be difficult to say anything which was not already more than adequately dealt with in the literature. Reference to the standard books on the subject shows that such works as Walsh's "Photometry"[1], the more detailed paper[2] in the Proceedings of the Optical Convention of 1926, and Harcombe's[3] paper in the same publication, cover the subject fairly fully.

The author, therefore, asks for consideration if some ground that is already familiar is covered in the present paper. It is first of all necessary, in a paper of this type, to state clearly the restrictions which are imposed on the subject for the particular purpose of the discussion. It should be understood, therefore, that the paper will be confined to photometry of that type of apparatus which projects a well defined beam as opposed to floodlighting and similar equipment which covers a relatively large solid angle. In the same way the assumption will be made that the lamps used can, in general, more conveniently be measured in kilowatts than in watts.

Such projectors are devices for redirecting light flux from undesired directions into others where its effect is required. It is usual to rate them in terms of intensity or candle-power, i.e., in terms of a theoretical point source which would give the same illumination in any predetermined direction as the projector being measured. This equivalent intensity is dependent on three factors:

(a) The brightness of the source.

(b) The area of the apparatus projected in the direction of observation.

(c) The mechanical efficiency of the apparatus, e.g., the reflecting power of the surface, the accuracy of the prisms, and so on.

This intensity bears no direct relation to the overall efficiency of the apparatus as a redirector of flux. Thus a small headlamp of low intensity may be more efficient than a large searchlight of enormous candle-power.

Incidentally, it should be observed that no instrument measures candle-power directly. Intensity is always measured indirectly by means of the illumination produced by it over a small area as compared with the illumination produced on a similar surface illuminated under known conditions by a source which has in turn been calibrated by direct or indirect reference to one of the international standards. In view of all these comparisons it is easy to understand the necessity for elaborate precautions if consistent results are to be obtained.

[1] J. W. T. Walsh, "Photometry." Constable, London, 1926.
[2] J. W. T. Walsh, Proc. Opt. Convention, 1926. pp. 378-387.
[3] S. Harcombe, Proc. Opt. Convention, 1926. pp. 388-406.

1. General and Theoretical Considerations.

Since all photometry is based on the application of the inverse square rule, it follows that the observed illumination multiplied by the square of the distance from the projector should give constant products. In actual fact this practically never happens. If measurements are made at varying distances from the projector it is found that the product first increases and then decreases as the distance is increased. This is due to two main effects:

(a) As the distance increases the "flashed area" increases and reaches a maximum value, either suddenly in the case of reflectors, or asymptotically in the case of certain types of dioptric apparatus.

(b) As the distance increases the absorption or scattering of the atmosphere increases with a resulting diminution in the illumination.

Minimum Distance for the Application of the Inverse Square Law.

If repeatable results are to be obtained the distance between the projector and the photometer must be so great that the difference between the actual value measured and the value which would be given in a vacuum at an infinite distance is within the experimental error. The determination of the least safe distance is in many cases a matter of some difficulty, and the papers already mentioned by Walsh[2] and Harcombe[3] deal with the calculation of this distance for a number of theoretical cases. In general, for the axial direction, the cross-over point, i.e., the point where the most divergent rays from the periphery of the apparatus intersect the line joining the observer and the luminous source and which is characterised by the fact that beyond it the intensity of the apparatus does not increase, can be computed from formulae of the type:

$$L = \frac{lD}{d}$$

where

L = distance of the cross-over point.
D = diameter of the projector.
l = distance from source to the edge of the projector.
d = diameter of source viewed from the edge of the projector.

The difficulty in applying this formula is in knowing what value to take for d. In an American specification for methods of measuring the candle-power of aviation lighting equipment, it is specifically stated that this dimension must refer to the

[2], [3], Loc. cit.

individual coils of a filament lamp, but even this does not meet all objections. In the case of an arc lamp, for instance, the brightness across the carbon varies rapidly from centre to side and the brightest spot can be presumed to be at the actual optical centre of the carbon. Thus, the maximum intensity can only be determined at an infinite distance and it is a matter of extreme difficulty to estimate the effect of the error involved by measuring it at anything less. Again, as has been shown[2], the distance to the cross-over point increases very rapidly for a small angular variation in the axis of the beam, and any errors in the accuracy of the optical system also act in the same direction. As an Appendix (A) to this paper I have inserted tables showing the distances of the cross-over point for parabolic mirrors using spherical and disc sources of various sizes, and also for dioptric apparatus with a Fresnel section, again using a spherical or disc source and making allowance for the effect of chromatic aberration. These tables assume a uniform brightness across the source, and can only be used as an approximate guide. The safest rule is to use the greatest available distance consistent with having sufficient illumination to get the readings.

Effect of Absorption.

It cannot be too strongly emphasised that a correction for atmospheric absorption or scattering should always be applied in the case of photometry of projectors. Experience suggests that these corrections are rarely less than 5 per cent. at, say, 500 feet, and may even be as great as 25 per cent. for the same distance under conditions which are not obviously misty. If, as sometimes in my own case, these measurements have to be carried out indoors in buildings which are occupied during the day, the effect of dust in the atmosphere is as serious as the effect of mist in outdoor work, and the same type of correction is necessary. The methods which can be adopted for the estimation of atmospheric absorption may be classified under two main groups:

1. Simultaneous readings of the projector and some standard source.
2. The measurement of the apparent candle-power at different distances beyond the cross-over point, using the actual projector itself as a source.

In applying the first of these methods it is convenient to have a standard projection apparatus mounted side by side with the apparatus under test, then by some convenient switching arrangement readings can be taken almost simultaneously on the two projectors from any particular photometric distance. A form of apparatus which was used by the author has consisted of a large lens with a powerful filament lamp behind it, which could be focussed up to give a reasonably narrow beam, and then by the insertion of a piece of ground glass between the lens and lamp a wide angled beam of uniform intensity could be obtained. This is necessary in order that errors are not introduced by variations of the direction in which the measurements are made from the different observation points. An alternative, and in some respects better method, is one that has been adopted by the Research Laboratories of the General Electric Company, to the members of which I am indebted for the information, which makes use of a telephotometer[4] to measure the brightness of a uniformly illuminated white screen at distances which are comparable with those being used for the actual observations.

The second method is simple in theory but less accurate in practice, owing to the difficulty of reading exactly in the same angular direction from the different distances. Many projectors vary so rapidly in intensity with slight variations in angle that the result of atmospheric correction measurements show weird and irregular variations. Whichever method is used the theory of the application of the correction is the same, and a convenient way of applying a correction is based on the well-known formula:

$$E = \frac{I_o}{x^2}\, 10^{-Kx}$$

where E = illumination at distance x
I_o = intensity of source
K = absorption constant.

This is written in the form:

$$\log\ (Ex^2) = \log I_o - Kx.$$

If the values of E as measured are multiplied by the values of x^2 the apparent intensity at distance x is obtained. It should be noted that as distance appears as x^2, it must be accurately measured. In general, it must be correct to 0.2 per cent. or 2 in. in 100 ft. This does not apply to the G.E.C. method of brightness measurement, where 2 per cent. error in x is immaterial. The logarithms of these are plotted against x and the value of log (Ex^2) is taken for $x = 0$. The use of linear logarithmic paper makes the method very quick and convenient for application on the field, and those who have experienced the tribulations of photometry on a cold night in an exposed position will realise that anything which makes for quickness is desirable. The nearness of these points to a straight line gives a measure of the accuracy of the observation and the uniformity of the atmosphere. A typical example of the correction for atmospheric absorption is given in the Appendix B. This is an actual instance of measurements that were taken on a piece of apparatus which we manufactured, and it will be seen that the candle-power readings, which varied actually from 270,000 to 870,000, were shown after correction for atmospheric absorption to yield approximately constant values of slightly over 1,000,000, which was the candle-power the apparatus would give in a theoretically clear atmosphere. It should also be noted that the calculated value for the cross-over point for this apparatus for a single coil of the grid was some 300 ft., and in both cases the values measured at a shorter distance were,

[2], Loc. cit.

[4] For details of the telephotometer, see J. M. Waldram. Illum. Engineer, XXVII (October, 1934), 311.

after correction for absorption, appreciably lower than those measured at greater distances.

Stray Light Correction.

It is usual to apply a correction to illumination readings for the stray light which is scattered on to the test plate from points outside the small cone joining the test plate to the apparatus. This is clearly necessary when what is desired is the intensity given by direct rays from the source in a clear atmosphere, although, on the other hand, it is sometimes pointed out that the illumination on the photometer is the sum of all the illuminations due to the light falling on it both directly and that which is scattered in the direction of the test plate from the beam. The second of these is obviously the practical figure, but since it depends on the atmospheric conditions it cannot be accepted for the purpose of standardised tests. With a highly concentrated beam, illumination just outside the peak direction may conceivably be due more to scattered light from the high flux intensity of the beam than it is to direct light from the source under normal conditions of measurement, which imply a slightly diffusing atmosphere.

The illumination at the test plate obviously consists of the sum of the contributions due to the intensity of the apparatus in the direction of the test plate, multiplied by the direct transmission of the atmosphere, plus the general illumination due to starlight, skylight, and so on, plus the scattered light from rays which lie just outside the small cone in which the test plate lies, plus the forward brightness of the atmosphere in the beam itself. There may also be secondary scattering due to the atmosphere surrounding the beam pencil being illuminated by the scattering of the light flux from the main beam. It is to be assumed that the term " direct transmission of the atmosphere " has a meaning apart from the scattered light. The direct measurement of atmospheric absorption by means of the inverse square law measures this direct transmission if the stray light is subtracted, which is usually done by putting an opaque object—a hat is very convenient—in front of and some distance away from the test plate and taking a reading of the residual illumination. This corrected figure is one which should be utilised for the calculation of the direct transmission of the atmosphere for substitution in the equations already quoted. The method of measurement of atmospheric absorption pursued by the General Electric Company's Research Laboratory, by the diminution of brightness in which the rays that are photometered are selected by a telescope, consists only of the direct rays from the source diminished by the real absorption, plus the brightness of the atmosphere in the beam itself. The flux in the pencil follows the same law as is implied in the inverse square measurement, and therefore the brightness of the atmosphere of the pencil is included in the measurement to the same extent as it is included in the measurement of the beam intensity after subtraction of the stray light correction measured by an opaque object in the main beam. Equivalent measurements are therefore given by the illumination from the projector minus stray light reading; the illumination from a standard source minus the stray light reading; and the brightness of a uniform source read directly, because each of these is a measure of the flux within the cone between the observation point and the limits of the source, all flux outside that cone being eliminated.

Effect of Focussing on the Photometer Screen.

Since the cross-over point varies for each direction of view, it follows that, for theoretical accuracy at any rate, it is impossible to measure the polar curve at any distance less than infinity. The axial value might be obtained at a distance of, say, 15 metres, whereas at, say, 1° away from the axis the distance required might be several hundred metres. These figures refer to a uniform source, and the case for a non-uniform source is even worse. It is a frequent practice to focus the projector on to the photometer at some convenient distance of measurement which is, for preference, beyond the cross-over point for the axial beam, and to measure the polar curve under these conditions. As far as the author is aware no attempt has been made to estimate the error introduced by so doing. It appears likely from general reasoning that the resultant polar curve is more accurate when obtained in this manner, provided the distance of measurement is relatively large.

The perfect projector, accurately focussed, gives an enlarged image of the source at infinity. The polar curve, therefore, should represent a measure of the variation in brightness across this image, and if the distance is reasonably great a curve relating brightness to the angular direction of the point measured when focussed at that distance should not depart greatly from the true value, were it possible to measure it. Calculations could only be carried out for particular projectors and sources, and the results could obviously only be applied with great caution to any other case. This is, however, a subject which might form part of a useful investigation if any member has the time to take it up.

The Effect of Errors in the Apparatus Itself.

No apparatus is perfectly made, and with small light sources of high intensity the effect of these errors though small is considerable. Their importance depends on the purpose to which the apparatus is to be put. For instance, a small extra divergence due to errors of manufacture may bring the peak intensity of a searchlight down by a large percentage, but they will not affect to a measurable degree the efficiency of the apparatus as reckoned by the total flux put into the beam. In the case of an airway beacon, for instance, the important thing is the efficiency of the beacon as a flashing mechanism. The effect on the eye depends on the mean value of the intensity during the flash and the period of the flash. In a particular instance where measurements were taken it was found that one apparatus gave a peak intensity of 874,000 candles, whereas previous apparatus which appeared to be no more accurately made gave a peak intensity of about 1,400,000 candles. When, however, the mean intensity was computed

for the beam and the effective flux in the flash was computed, the efficiencies of the two pieces of apparatus were found to be 43.5 per cent. and 41.5 per cent. Thus, although one peak intensity was almost twice that given by the other apparatus there was practically no difference in them as regards their effectiveness for the purpose for which they were intended and in fact the one with the lower intensity was slightly the more efficient.

Photographs of the flashed area form an excellent means of estimating the effect on the efficiency of filament and mirror distortions. It is essential that the photographs should be taken from the same distance as the photometric measurements are made, and this means that a telephoto lens is required. The example shown in the photographs with this paper were taken with a lens of 160 in. focal length at a distance of 240 ft. If the distances become too great

Fig. 1. Appearance of perfect mirror.

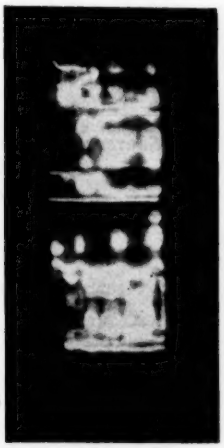

Fig. 2. Appearance of mirror in best position.

it is frequently difficulty to get accurate photographs owing to the presence of air currents which tend to spoil the definition with long exposures. The photographs show (1) the appearance which would be given by a perfect mirror obtained by wrapping a piece of tissue paper round the lamp bulb, and (2) the appearance with a line filament showing the errors due to irregularities in the filament and in the mirror.[5]

2. Measurements.

It is not possible in the time at my disposal to do more than comment on a few of the factors which have appeared to me to be of particular practical importance. I do not propose to discuss the types of apparatus which are available or the normal corrections which should be applied, as this again is all text-book stuff. In the case of the light source itself, what is usually needed is the candle-power in the direction of the peak given by the apparatus, and this is a matter which can be determined directly by means of straightforward photometry.

Light Source.

It is usually essential to have a curve of the total lumen output of the lamp as a function of the power input, as it may not always be convenient to run the lamp at rated volts during the tests, although the intensity of the apparatus as finally reported should be given in terms of the standard output for that particular lamp at the rated volts. A correction may therefore be needed for two reasons: first, that the measurements were not made at the rated volts; and secondly, because the individual lamp used may differ somewhat from the mean value for that particular type. The dimensions of the source are most conveniently obtained by means of photography, and if a fairly long focus lens be used for this photograph and a scale included in the picture, the actual dimensions of the source can be determined with sufficient accuracy. It is scarcely necessary to mention such practical questions as noting that the burning position of the lamp during the determination of its characteristics should be the same as in the case when it is installed in the projector, and in the case of gas or oil apparatus the chimney effect in the projector may cause an appreciable change of the candle-power given by the burner.

Peak Intensity.

In preparing to determine the peak intensity of a projector the first essential is to have the apparatus properly focussed and aligned. The question of focussing to infinity or focussing on to the photometer has already been discussed, but whichever is attempted it will be found that substantial variations arise due to errors in the optical system or to the non-uniformity of the source. It is this variation which is the origin of the usual practice in focussing on the photometer, since the best position of the source usually has to be determined by means of measurements at the point of the test plate. In this connection a photronic cell has been found very useful, as one operator can read the cell while the other makes small adjustments in the position of the light source and the projector. Perhaps it may be said at this point that the use of a telephone avoids many misunderstandings. The actual measurements can conveniently be carried out by some form of portable photometer, the particular type is not important as any such apparatus should be calibrated against a standard lamp both before and after the test. Where measurements are carried out under laboratory conditions the main difficulty is in getting a sufficient range and avoiding reflections from walls and other pieces of apparatus. The actual photometry in this case is most easily carried out by means of a fixed photometer head and an adjustable light source, which is itself standardised. Where colour differences exist, either inside or outside the laboratory, it is essential to use some form of colour filter which

[5] H. J. A. Turner, "Light and Lighting," Nov. 1937, p. 328.

can subsequently be calibrated by means of its spectro-photometric curve and the use of the I.C.I. standard eye sensitivity curve.

3. Polar Distribution.

The term "polar curve" is loosely applied to any curve showing the relation between intensity and angle of emission, whereas it should strictly be applied only to such a curve when plotted in polar co-ordinates. On the other hand the polar curve is what is actually measured, however the results may be plotted. The general principles discussed above as regards the distance required, and so on, apply here, but as the angle from the peak increases, the intensity decreases, and at the same time the necessity arises for greater distances in order to obtain a true value. For these reasons the accuracy away from the peak becomes substantially less, and it is probable that the curve of light distribution is in general less certain than the absolute value of the candle-power. Since relative measurements only are required in this case, a photoelectric or a photovoltaic cell is very convenient. It is far more satisfactory where possible, to have the projector mounted on a rotating table so that the test plate may be kept in a fixed position, and this applies more to outdoor measurements than it does to indoor. In Appendix C, a calculation is given showing the effect on the polar curve of a particular type of apparatus where there is a small but steady slope in the plane of the observation field. In the case of projectors of small divergence, variations in the slope of the field which are almost imperceptible can cause surprising changes in the shape of the polar curve.

Determination of Flux.

The most satisfactory way is undoubtedly by means of an integrating sphere or cube, but in so many practical cases its use is impossible. In the case of an aerodrome floodlight for instance, which measures perhaps 20 ft. × 10 ft., the size of cube would be outside the region of practical politics. One is forced, therefore, in general to a determination of the polar curve in several planes and computation from the results. Standard books on the subject have discussions as to the number of planes in which such polar curves should be made according to the type of distribution given by the apparatus, but for many practical purposes it suffices to assume an elliptical distribution, i.e., that there are two planes of symmetry at right angles, and the calculation of flux can be made from the mean of these two curves.

In presenting this paper, the author is conscious that he has departed somewhat from the summary circulated prior to the meeting, and that he has only been able to deal with a few of the many problems on the subject which have attracted his attention.

APPENDIX A.

Calculations of "Cross-Over" Point.

Walsh[2] has worked out formulae for the position of the cross-over point for various types of projector. The following is based largely on his work:

PARABOLIC MIRROR.

Let f = focal distance.

L = distance of cross-over point measured from the plane of the aperture of the mirror.

ρ = radius of source.

R = radius of projected aperture of mirror.

(a) *Spherical Source.*

It is shown that

$$L = \frac{R^2}{4f} + \frac{R}{\rho}\left(f + \frac{R^2}{4f}\right)$$

when ρ is small compared with R, and L is measured from the mirror surface.

For L as defined above

$$L = \frac{R}{\rho}\left(\frac{4f^2 + R^2}{4f}\right)$$

It is more convenient to measure L, R, and ρ relative to the focal distance, so that using subscripts for these relative values:

$$L_1 = \frac{R_1}{\rho_1}\left(1 + \frac{R_1^2}{4}\right)$$

Values of this function are given below for different values of R_1 and ρ_1. These are also plotted on Fig. 3.

	ρ_1 = .005	.01	.02	.03
R_1=0	0	0	0	0
.2	40.4	20.2	10.1	6.7
.4	83.2	41.6	20.8	13.9
.6	130.8	65.4	32.7	21.8
.8	185.6	92.8	46.4	30.9
1.0	250	125	62.5	41.2
1.2	326	163	81.5	54.3
1.4	417	208	104	69.7
1.6	525	262	131	87.5

(b) *Disc Source.*

By similar reasoning, for this case

$$L_1 = \frac{R_1}{\rho_1}\left(\frac{1 + \frac{R_1^2}{4}}{1 - \frac{R_1^2}{4}}\right)$$

which clearly approaches ∞ when R_1 approaches 2.

	ρ_1 = .005	.01	.02	.03
R_1= .2	40.8	20.4	10.2	6.9
.4	86.7	43.3	21.7	14.5
.6	143.8	71.9	35.9	24.0
.8	221	110	55.2	36.8
1.0	333	167	83.3	55.0
1.2	510	255	128	85.2
1.4	817	408	204	136
1.6	1460	726	363	243

See Fig. 3.

DIOPTRIC SYSTEMS (Refracting Prisms).

(a) *Spherical Source.*

The case has been worked out fully in a previous publication[6], making allowance for the chromatic aberration inevitable with this type.

If θ = Maximum angle from the horizontal (subtended by the extreme element).

δn_R = chromatic dispersion for red light measured from the wave length for which the lens was designed (= .004 for Lighthouse Crown).

n = refractive index.

Then $L_1 = \dfrac{\tan\theta}{\rho_1 \zeta \cos\theta - \eta \delta n_R}$

where $\zeta = \dfrac{-\cos\theta\,(n^2 - \sqrt{n^2 - \sin^2\theta})}{n^2 - \sin^2\theta - \sqrt{n^2 - \sin^2\theta}}$

$$\eta = \frac{n \sin\theta}{n^2 - \sin^2\theta - \sqrt{n^2 - \sin^2\theta}}$$

Tables for ζ and η are provided in the previous publication.

[2] Walsh, Proc. Opt. Convention, 1926, pp. 378-387.

[6] W. M. Hampton, Trans. Opt. Soc., Vol. XXX., No. 5, 1928-29, pp. 185-206.

$R_1 = \tan\theta$

ρ_1 =		.005	.01	.02	.03
R_1 = .2	i.e., θ = 11.3°	67	25.0	11.1	7.2
.4	21.8	200	57.2	23.6	14.8
.6	31.0	∞	120	40.0	24.0
.8	38.6	∞	267	61.5	34.8
1.0	45.0	∞	1000	91.0	47.6

See Fig. 4.

The reflecting prisms can be treated as though they were part of a normal silvered mirror, since there is no appreciable chromatic aberration consequent on two reflectors in opposite senses.

(b) *Disc Source.*

The equation in this case becomes:

$$L_1 = \frac{\tan\theta}{\rho_1\zeta\cos^2\theta - \eta\delta n_R}$$

ρ_1 =	.005	0.1	.02	.03
R_1 = .2	67	26	11	7.2
.4	200	63	25	16.0
.6	∞	∞	48	29
.8	∞	∞	95	50
1.0	∞	∞	193	83

See Fig. 4.

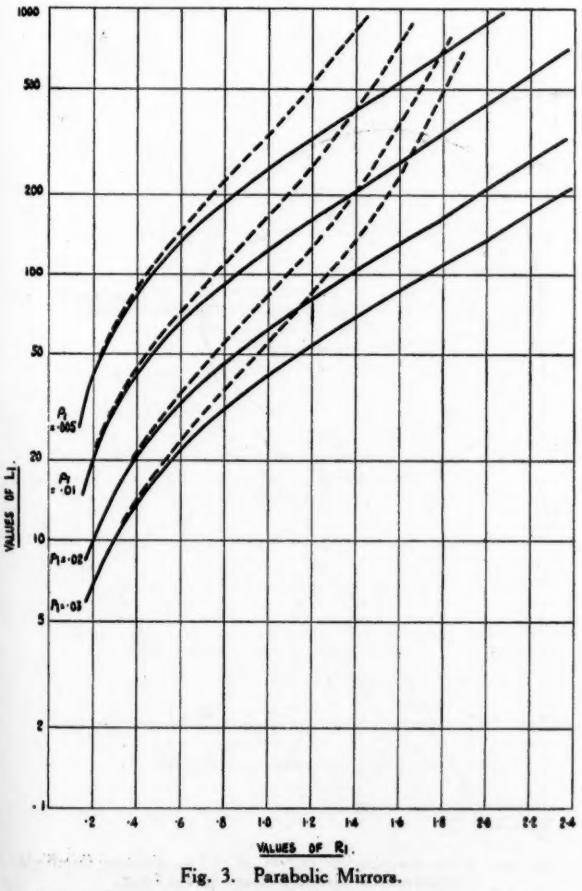

Fig. 3. Parabolic Mirrors.
Spherical source ——— Disc source - - - - - -

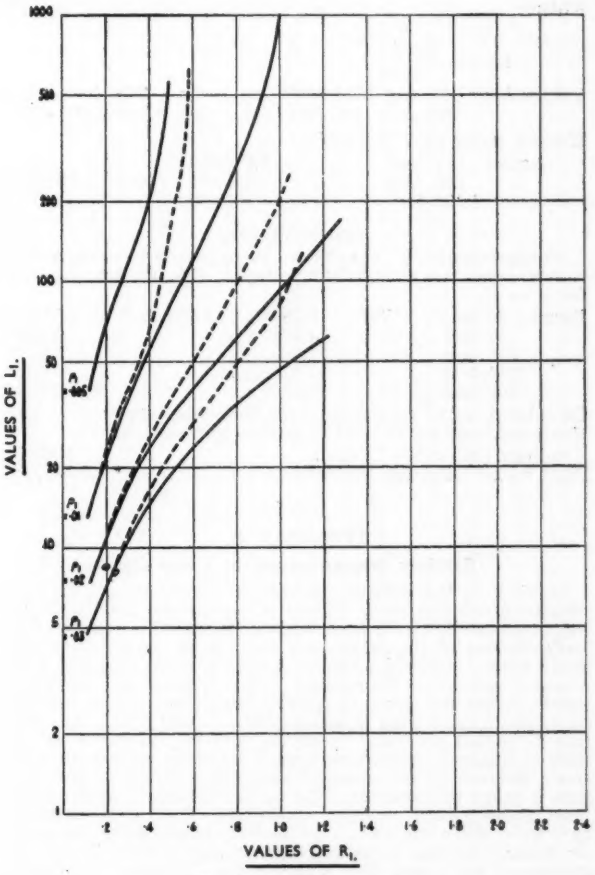

Fig. 4. Dioptric System.
Spherical source ——— Disc source - - - - - -

APPENDIX B.

Typical Example of Corrections for Atmospheric Absorption.

The measurements were made on a 16-in. projector (parabolic mirror) with a class A1 tubular vertical burning gas filled lamp 30-volt 900-watt. Grid filament 14 × 12 mm. Nominal horizontal candle-power normal to filament plane of 2,050; guaranteed peak candle-power of projector 955,000. Distance of cross-over = 300 ft., based on one spiral.

OUTDOOR VALUES.

The night on which measurements were made was hazy, and three ranges were chosen at which illumination readings were taken.

After correction for voltage variations, the values were:—

Range	177 feet	(Ex^2) 869,000
	300 ,,	756,000
	1,125 ,,	272,000

From $I_o = \frac{Ex^2}{\tau^x}$ τ = Relative trans./unit distance.

Subscripts refer to two sets of readings.

$$I_o = \frac{E_1 x_1^2}{\tau^{x_1}} = \frac{E_2 x_2^2}{\tau^{x_2}}$$

whence

$$\log \tau = \frac{\log \frac{E_2 x_2^2}{E_1 x_1^2}}{x_2 - x_1}$$

Values from 177 and 1125 feet $\log \tau = -2.81$ (per mile)
300 and 1125 feet $\log \tau = -2.83$ (per mile)

Whence using $\log \tau = -2.82$.

Range		I_o =		
	177 feet		1,075,000	
	300 feet		1,086,000	mean 1,089,000.
	1,125 feet		1,108,000	

INDOOR VALUES.

Measurements of absorption were made by means of a 10 kW. lamp run at constant voltage. The figures obtained were:—

Range					
40 feet ...	(Ex^2)	15,190	...	corrected I_o	16,870
60 feet ...		14,040	...		16,430
100 feet ...		11,800	...		15,320
150 feet ...		11,020	...		16,300
200 feet ...		10,000	...		16,870

Calculated $\log \tau$ (per mile) over the whole range = −6.00
Measured candle-power of projector corrected for voltage (200 ft.) 588,000
Final value weighted for distance 1,095,000

APPENDIX C.

Outdoor Measurements of Polar Curves.

In view of the difficulty which is always experienced in obtaining reliable polar curves of aerodrome floodlights by field measurements, it is of interest to estimate the effect of irregularities of the aerodrome surface on the shape of the polar curve. Usually field measurements are found to give a much narrower distribution than is given by measurements under the more controlled conditions of the laboratory, and indeed than is actually true. The reason for this may be stated generally by saying that the floodlight on the field is focussed to give maximum intensity at eye level at some distance in the straight ahead (0°) direction and less care is taken to ensure that the peak intensity is at the same level above ground in other directions. Even if all possible care were taken the surface of the field is generally too wavy or sloping for the measurements of intensity to be at the maximum all round the polar curve. Under laboratory conditions where the floodlight is mounted on a turntable or where some equivalent method can be employed, it is easy to ensure that all measurements are taken in the central plane of the beam, and the horizontal polar curve so obtained will represent the maximum intensity in the vertical sense at each angle of azimuth.

In order to estimate the effect of irregularities in the plane of measurement, it is necessary to find a mathematical expression for the polar distribution. The Chance 5 kW. dioptric aerodrome floodlight may be taken as a typical example, and the equation of the polar solid for this floodlight is as follows:—

$$I_{\theta\beta} = I_o \cos\theta \cos^3\left(\frac{\pi\beta}{2B}\right) \quad \ldots\ldots(1)$$

where

I_o is the axial intensity.
θ is the horizontal angle in the central plane.
β is the vertical angle from the central plane.
2B is the gross vertical spread of the beam.
$I_{\theta\beta}$ is the intensity in the direction (θ, β).

If the plane of measurement is identical with the central plane, the polar curve will be:

$$I_\theta = I_o \cos\theta \quad \ldots\ldots(2)$$

If the plane of measurement is inclined to the central plane of the beam, the measurement of axial intensity would be unaffected, but the apparent intensity at other angles would be altered. The figures involved may be calculated exactly for the polar solid given by equation (1), and by comparison with equation (2) it would be possible to make a qualitative estimate of the effect on floodlights with some different polar distribution.

Consider a plane of measurement which is inclined at an angle α to the central plane of the beam, and which intersects the latter along the direction of peak intensity (the OX axis). The equation to this plane is:

$$Y = Z \tan \alpha \quad \ldots\ldots(3)$$

or

$$\tan\beta = \tan\alpha \sin\theta \quad \ldots\ldots(4)$$

By eliminating β from equation (1) and (4) we have the polar distribution which would be given by actual measurement in the inclined plane; for $\alpha = 0$ this would be given by equation (2), but for other values of α the calculation is best made point by point. This has been done for several typical cases, and the results are shown diagrammatically. Fig. 5 shows the case of a beam of gross vertical spread of 2° and angles of inclination of the plane of measurement of 0°, 0.5°, 1°, and 2°. Fig. 6 shows the case of a beam of

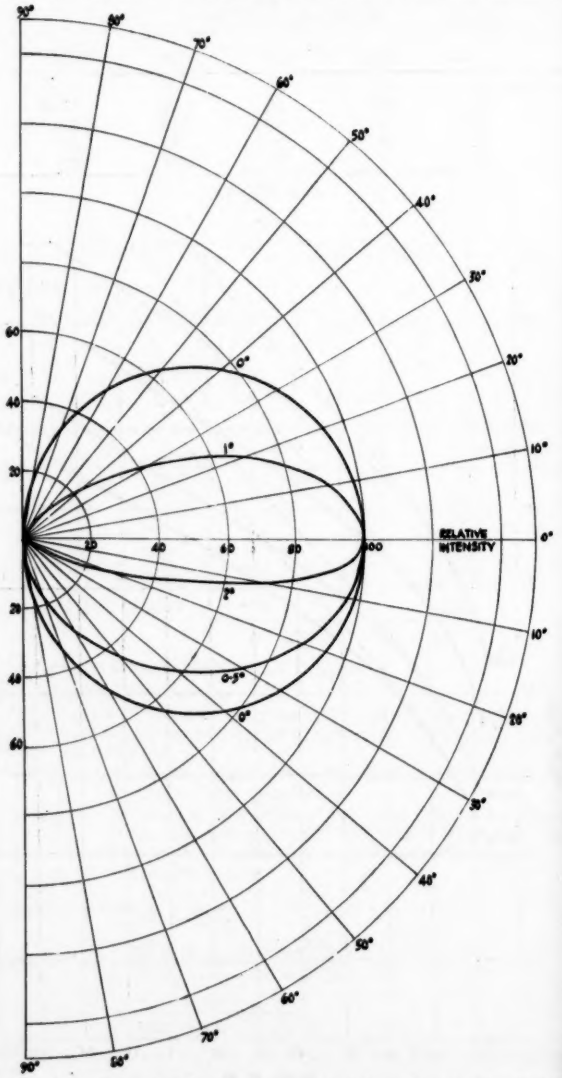

Fig. 5a. Polar distribution curves of 5 kw. dioptric floodlight measured in planes inclined to the beam.
Gross beam spread 2B=2°.

gross vertical spread of 4° and angles of inclination of the plane of measurement of 0°, 0.5°, 1°, 2°, and 5°.

Consider a vertical spread of 2° as in Fig. 5. It may be seen that a slope of 0.5° (i.e., 1 in 115), which is scarcely likely to be appreciated on an aerodrome, particularly at night, reduced the intensity at 45° by about 30%. A slope of 1° (1 in 57) reduced the intensity by 80%. These reductions are independent of the actual intensity and of the shape of the polar curve in the horizontal sense, and may be applied to other floodlights than the one cited above. In practice, of course, the aerodrome surface does not slope uniformly, and there would be erratic reductions in intensity rather than the smooth reductions shown in the diagrams. These may always be estimated by measuring the aerodrome surface so as to give the effective slope to each point, but the important result of this argument is that any irregularities will reduce the apparent intensity at angles away from the axis, and will make the polar curve narrower than it should be.

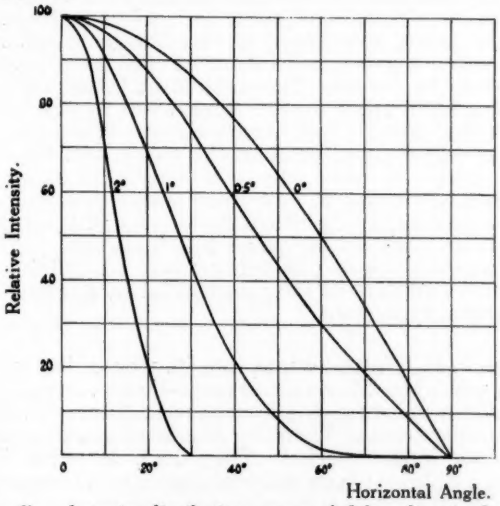

Fig. 5b. Intensity distribution curves of 5 kw. dioptric floodlight measured in planes inclined to the beam. Gross vertical spread 2°.

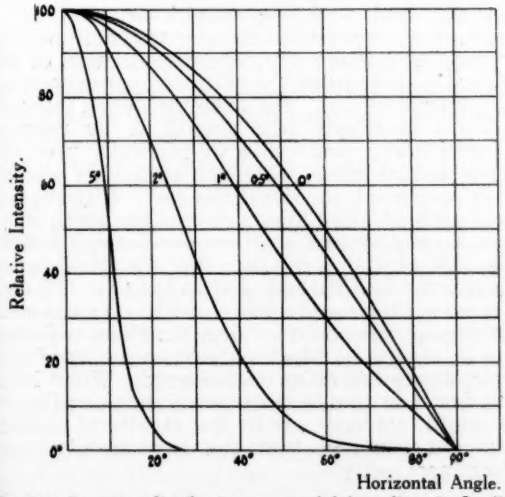

Fig. 6b. Intensity distribution curve of 5 kw. dioptric floodlight measured in planes inclined to the beam. Gross vertical spread 2B=4°.

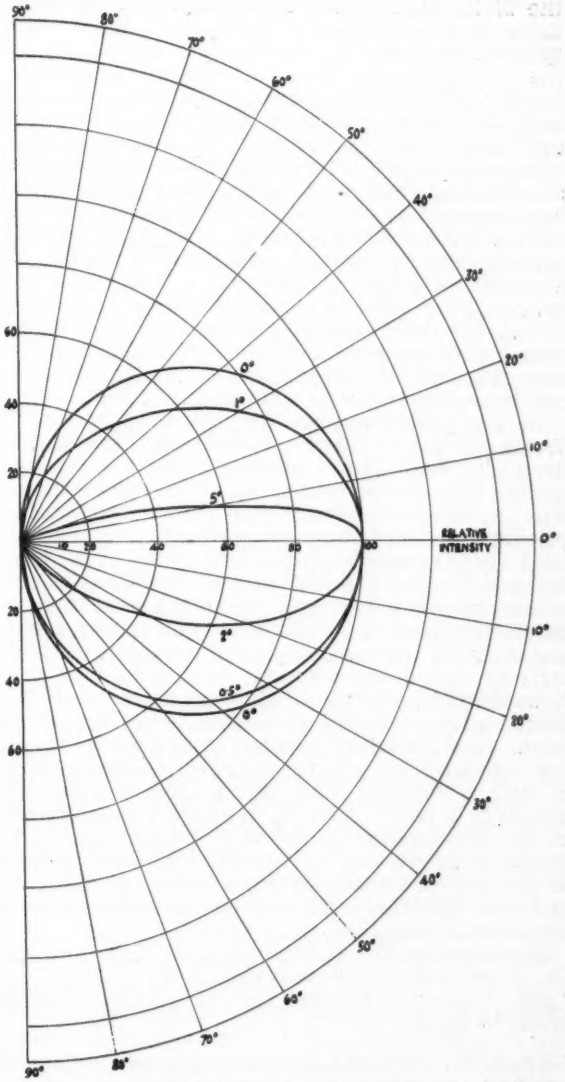

Fig. 6a. Polar distribution curves of 5 kw. dioptric floodlight measured in planes inclined to the beam. Gross beam spread 2B=4°.

DISCUSSION

Dr. J. W. T. WALSH, in opening the discussion, said that Dr. Hampton, with characteristic modesty, had suggested that the subject was dealt with in various textbooks. Those who had had some experience of practical photometric measurements with projection apparatus would agree that the theoretical treatment in textbooks was not generally very helpful. They had been fortunate in hearing a paper by a specialist in this field, and he, for one, had enjoyed listening to Dr. Hampton.

Dr. Walsh referred to various difficulties encountered in early measurements of searchlights at

the National Physical Laboratory. In addition to those mentioned by Dr. Hampton—such as atmospheric absorption—there was a problem arising from the fact of Bushey Park being open to the public, namely, the presence of curious spectators. A special staff was necessary to keep them away from the line over which the measurements were being made.

In later years their experience had been less with searchlights than with motor car headlights, the measurement of which involved problems generally similar to those discussed by Dr. Hampton. Originally measurements were made at a distance of 25 ft., and a calculated value of "apparent candle-power" was given. Subsequently, although 25 ft. was still retained for the distance of measurement, a plot of illumination measurements over the illuminated portion of a vertical screen was substituted. Measurements are now made at a distance of 100 ft.

In the photometry of projection apparatus, Dr. Walsh continued, one is between the devil and the deep blue sea. If one steered round the Scylla of getting the photometer too near to the projector one was bound to come to grief on the Charybdis of not getting sufficient light to measure. This applied particularly to measurements near the edge of the beam, because, besides the fact that the candle-power decreases as one moves away from the axis, the measurements have to be made at greater and greater distances for the same degree of accuracy. It might well be considered whether, in this field of work, it would not be better to abandon measurements of illumination, and instead measure what the French term "éclat stellaire," which is equivalent to measuring with a telephotometer the effective candle-power at such a distance that the projector diminishes almost to a point. This is, in effect, a measurement of the illumination at the eye in mile-candles. It would be interesting to hear Dr. Hampton's opinion of the idea of measuring the effective candle-power of a searchlight at a distance of one or two miles in the manner described.

In conclusion, Dr. Walsh said that he fully endorsed Dr. Hampton's condemnation of the horrid term "polar curve," and hoped that his protest would be taken to heart.

Mr. E. W. CHIVERS said that he knew only too well the hosts of difficulties appertaining to the photometry of projectors, which only served to emphasise the need for attention to accuracy in such measurements. Dr. Hampton had mentioned one frequent difficulty—the small illumination available for measurement. Searchlights, however, were of such power that one often had too much light—a source of intense brightness which is neither a disc nor a sphere. a large reflector, and a very powerful beam. The cross-over point was probably a long way away, and it was necessary to take measurements at several positions across the beam and to make the measurements at a distance as nearly equivalent to infinity as possible. For the experiments with which he was familiar they were fortunate in having a range of some 6,000 ft., which certainly was conducive to accuracy in regard to cross-over points, but accentuated the difficulty of allowing for atmospheric absorption—a problem with which they had been occupied for many years. He might mention that the method adopted by the G.E.C. Research Laboratories was one that had been in use at Biggin Hill for some years. He was not much impressed by methods based on calculated atmospheric absorptions, because conditions were apt to be very different in a valley from what they were at the top of a hill. It was necessary to use a method that applied over the whole range.

In actual practice, unfortunately, matters never turned out as one desired. Measurements of atmospheric transmission were invariably made every quarter of an hour during a test, but, even so, the fluctuations of the condition of the atmosphere were really astounding. A convenient method of measuring transmissions was very desirable. In focussing and aligning searchlight projectors great difficulty was often experienced owing to the very narrow beam to be tested. The method of "flashing" had been used in order to determine when focussing, and correct alignment had been secured. When the projector was truly aligned on the object and the lamp was truly in focus the whole reflector should be flashed. In order to determine when this condition was realised, the flashed reflector was photographed with the aid of a powerful telescope. Whilst measurement was not being made at infinity the method had proved very successful in aligning and focussing projectors.

Mr. J. M. WALDRAM said that he would like to confirm what Mr. Chivers had said—that at Biggin Hill a method of measuring atmospheric absorption similar to that used at Wembley had been in use, and for a much longer period. They had, however been using a different type of telephotometer. It seemed to him remarkable that photometric measurements were in general concerned with the measurement of candle-power. Yet this was not what it was needed to know. Searchlights and floodlights were there to illuminate something, and problems might be simplified if measurements were made directly of the illumination they furnished under the conditions of use, or some empirically standardised conditions approximating to the conditions of use. For example, when testing an aerodrome floodlight, why should it be necessary to adopt measurements at a theoretically prescribed distance of two miles, when the apparatus would be used at very much smaller distances? With regard to the remarks of Mr. Chivers on the focussing of projectors, he suggested that it was correct and sufficient to measure at such a distance that the whole area of the projector was flashed, and so long as that condition obtained the candle-power might be measured at any distance. He could confirm Dr. Hampton's statements in regard to the enormous amount of atmospheric absorption often encountered. When he and others first had to deal with aerodrome floodlighting they could scarcely credit the results of measurements, and assumed that the instrument must be reading incorrectly.

Mr. S. HARCOMBE said that he would like to have Dr. Hampton's opinion upon the effect of the focal

length of the projector on the candlepower of the beam. At Portsmouth he was specially concerned with searchlights. For a number of years they had dealt with this question of focal length, using the same source of light and the same aperture and making allowances for variations in atmospheric absorption; and they did find a difference in the final result. This had been confirmed by experiments at Biggin Hill. He understood that long continued researches at the National Physical Laboratory had shown that the two-station method and the screen method of measuring atmospheric absorption led to very similar results. At Portsmouth they usually preferred to use the two-station method. The ranges were of the order of 3,000 to 6,000 feet, and they were fortunate in having a 48 in. parabolic mirror with a special lamp. If a night were selected when conditions were clear, it was found that, using the two-station method, they could rely on the determination of the corrected candlepower of the beam, and could correlate with results on any other night. Local fogs and mists did, of course, affect the values considerably, but the method was quite an easy one for getting convenient records.

He wondered whether the divergence of the beam could be adequately defined. Could Dr. Hampton give any guidance as to the divergence of a beam when put out of focus? Should the usual method of 1/10th of maximum be applied?

When an image of a source of light is projected, which is essentially what occurs with a projector, the variation in brightness of the image should agree with that across the source. But in practice this was not the case. The variation in brightness from the centre to the edge might be very considerable.

Mr. H. J. A. TURNER stated that he had found photographic observations of flashed area very helpful in checking the candlepower of a beam. The apparatus used for the purpose consisted simply in a form of camera with a long focus lens, which takes a photograph of the mirror from the viewpoint of the test plate. One thus obtained a permanent record of the flashed area and the product of this flashed area and the brightness of the source gave one an indication of the candlepower that might be expected independently of measurements of atmospheric transmission.

He had some sympathy with Mr. Waldram's suggestion that candlepower measurements did not give a true indication of the usefulness of a floodlight, but there did not seem any other convenient basis of assessment. Possibly an isofootcandle diagram might be plotted, but everyone would recognise the difficulties and labour involved, and to obtain a survey of light on the ground as viewed from above did not seem to be a practicable proposition

Colonel C. H. SILVESTER EVANS agreed that there was not much practical information on this topic to be found in textbooks. He would like to suggest that this paper should be published by the Society *in extenso*. The department with which he was concerned was working on this type of problem, and he had no doubt that the paper would prove of value to them, as there was little practical information available on this problem.

Several speakers had discussed the purposes to be served by searchlights. In his own experience he was concerned mainly with what could be seen from the searchlight. This involved quite extensive investigations. Tests involving distances of over seven miles—not an easy range to obtain in this country—were necessary. The problem of determining the visibility of an illuminated target, as seen by an observer using the searchlight, had involved prolonged measurements carried out under conditions of atmospheric absorption which were often trying. It was difficult to say what order of accuracy could be assigned to peak measurements in these circumstances. With such sources of light as the arc inaccuracy in burning and difficulty in focusing were real obstacles. Dr. Hampton had referred to tests of a 16-in. reflector and appeared to base his final figures for the candle-power on the results of one night's measurements. He himself would not care to cite measurements on less than 1,000 determinations where atmospheric absorption was involved. "Efficiency," which had been mentioned in the discussion, was a term he hesitated to use—its meaning was peculiar to the purpose for which the apparatus was applied.

Mr. J. S. Dow expressed his interest in Dr. Hampton's confirmation of the important part played by absorption, even when distances involved were moderate. He was reminded of some work which he had done under Professor Ayrton about thirty-five years ago. The latter mentioned experiences with tests of searchlights conducted across a valley, when it was found that the dust caused by workers going to and fro when commencing and finishing their labours affected the atmospheric absorption and gave rise to abnormal measurements. A confirmatory experience was recorded when certain photometric tests were made in a long gallery, occasionally used for dancing classes during the day. On such occasions the absorption was abnormal and results were affected. The fact that pronounced and variable absorption might take place even when the atmosphere is apparently clear might well have a bearing in other fields of work—for example, it might help to explain apparently unaccountable variations in brightness and visibility observed in artificially lighted streets.

He quite understood that Dr. Hampton's paper was not concerned with floodlighting projectors and similar apparatus in connection with which distribution of losses of light and efficiency were of importance. It would, however, be of interest to know what was the most expeditious method of successively determining and comparing the flux of light emitted by the source, the flux emitted by the projector and the proportion of the latter actually received on the object illuminated. Would it be possible to evaluate the total light in the beam if it were received on a target